REMARKS

Claim Rejections – 35 USC § 112

Claim 50 is rejected under 35 U.S.C. 112, first paragraph, because the specification, while being enabling for claims 26-30, 32, 38, 47, and 52 given the broadest and reasonable interpretation of the specification these claims pertain merely to a mulch that is colored as an indicator and does not involve any chemical reactions (specification page 10 line 14-15), the specification does not reasonably provide enablement for claim 50. The specification does not enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the invention commensurate in scope with claim 50. The specification does not disclose what makes the color change or fade, is it a chemical process? How does the chemical process work and what are the chemicals and reactions involved?

It was known in the art at the time the invention was applied for that a dye can fade, disappear or change color. As shown in the Science News article attached, a dye called thymol blue, which is the color red can change colors as the acidity changes by adding sodium hydroxide.

Examiner maintains that one of ordinary skill in the art would ask is it a chemical process, how does the chemical process work, what chemicals and reactions are involved? Claim 50 merely reads that the color changes in response to a lack of fertilizer. The claim makes no reference to acidity/base/pH.

The specification states on page 3 that basic soil chemistry is modified b adding to the soil for example, calcium products to provide pH control, and flyash or like

products to provide pH control as well as micronutrients. These are some of the basic components of fertilizer. Therefore one of skill in the art would understand that the process is a chemical process.

Therefore, claim 50 is enabled.

Claim Rejections – 35 USC § 102/103

Claims 26, 27, 28, 29, 30, 52 are rejected under 35 U.S.C. 102(b) as anticipated by U.S. Patent No. 4,932,156 to Underwood or, in the alternative, under 35 U.S.C. 103(a) as obvious over U.S. Patent No. 4,297,810 to Hansford in view of U.S. Patent No. 2,526,938 to Davis et al.

Regarding Claims 26-30 and 52, Underwood teaches a colored mulch product (Underwood abstract line 1) wherein the color fades or disappears (Underwood abstract line 2) in response to a lack of nutrient or fertilizer in the mulch (Underwood abstract line 4 "ambient weather conditions"; the examiner views "nutrient" as water and when it rains, rain is an element of ambient weather conditions, objects inherently tend to appear vibrant. As the object dries (i.e. as it losses the nutrient water) it will inherently fade.

Underwood relates to retarding the fading color of mulch. Underwood relates to applying a brown color-control solution to the surface of the mulch so that the brown color of the mulch does not fade due to sunlight or other weather conditions. Therefore, Underwood specifically teaches that the dye added to the mulch will not change color based on ambient weather conditions, i.e., nutrient as water. With regards to claim 26, the claim requires that the dye indicate to a user environmental conditions of the soil. Since the dye of Underwood I not effected by sunlight or ambient weather, it cannot indicate environmental conditions to a user.

Therefore, claim 26 is not anticipated or obvious over Underwood. Regarding claim 27, for the reasons stated above for claim 26, claim 27 is not anticipated or obvious over Underwood.

With regard to claim 28, since the dye of Underwood cannot change colors based on ambient weather conditions, it cannot indicate to a user the acidity of the soil. Underwood does not discuss whatsoever that the dye indicates the acidity of the soil. Therefore, claim 28 is not anticipated or obvious over Underwood.

Claim 29 requires the dye indicate to a user the moisture content of the soil. Since Underwood teaches applying a dye which is not effected by ambient weather conditions including rain, it cannot indicate to a user the moisture content of the soil. Therefore, claim 29 is not anticipated or obvious over Underwood. Regarding claim 30, Underwood does not teach or relate to the dye indicating the chemical content of the soil. Therefore, claim 30 is not anticipated or obvious over Underwood.

With regards to Claim 50, the claim requires that the color fade or disappear in response to a lack of fertilizer. Underwood specifically teaches a dye which retards fading, therefore Claim 50 is not anticipated or obvious over Underwood.

Regarding claim 52, Underwood does not teach a method wherein a mulch changes colors based on conditions of the soil and in response to this chemicals are added to the soil. Since Underwood teaches a dye that retards fading and keeps the brown color, it cannot indicate the conditions required by Claim 52. Therefore, claim 52 is not anticipated or obvious over Underwood.

Regarding Claims 26, 28, 29, 30 and 52, Hansford teaches a colored mulch (Hansford 2 line 14) and the importance of moisture (Hansford Col. 2 line 63) to the plants thus indicating

general knowledge in the field of the plant husbandry that it is desirable to monitor the moisture conditions and to provide adequate moisture to ensure healthy development and that it is known to color mulch. Hansford is silent on the mulch fading in response to a lack of nutrient/chemical (i.e. water). However, Davis teaches a colorant additive that changes color as an indicator that water (i.e. nutrient) is present or absent (Davis Co. 1 line 35-41). It would have been obvious to one of ordinary skill in the art to modify the teachings of Hansford with the teachings of Davis at the time of the invention for the advantage of the known ability to monitor the moisture content as taught by Davis to ensure healthy growth and development of plants. The modification is merely the selection of a known alternate equivalent selected for the known advantage of its indicator properties. It would be obvious to one of ordinary skill in the art to perform the method step to add water (i.e. chemical) to the mulch when the mulch appears to have a low moisture concentration.

Hansford relates to a hydromulch, or a sprayable mulch. As stated in Hansford, it is preferred that the mulch composition include a dye or coloring agent, such as Calcozine Green. While green dye is preferred for aesthetic reasons, other colors may be used. The coloring agent is used chiefly for aesthetic purposes, in that it serves no mechanical or organic purpose in the composition. The coloring material functions to show the operator of the spraying equipment what areas have been colored with hydromulch and thereby avoid gaps and overlapping in the application of the hydromulch. The hydromulch of Hansford is used by placing it in tanks which are subsequently filled with water to provide a pumpable suspension. Hansford does not teach that it is desirable to monitor water conditions. The Examiner states that Davis teaches a colorant additive that changes color as an indicator that water is present or

absent. Obviously since Hansford is a hydromulch, by placing a moisture indicator into it, it will always indicate the presence of water. Therefore, there is no reason to combine Hansford and Davis.

Because there is no reason to add a moisture indicator into a hydromulch, there is no reason to combine Hansford and Davis. Therefore, Claims 26, 28-30 and 52 are not obvious over Hansford in view of Davis.

Regarding Claim 27, Hansford as modified teaches fertilizer and this inherently teaches nitrogen, phosphorous, and potassium fortifiers (Hansford Col. 5 line 4)

For the reasons stated above for claim 26, claim 27 is not obvious over Hansford in view of Davis.

Claim 32 is rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 4,297,810 to Hansford in view of U.S. Patent No. 2,526,938 to Davis et al as applied to claim 26 above, and further in view of U.S. Patent No. 5,734,167 to Skelty.

Regarding Claim 32, Hansford as modified teaches coloring the mulch, but is silent on the dye is florescent. However, Skelty teaches it is old and notoriously well-known to dye agricultural products with florescent dye allowing the mulch to glow in the dark (Skelty Col. 1 line 35-45). It would have been obvious to one of ordinary skill in the art to further modify the teachings of Hansford with the teachings of Skelty at the time of the invention since the modification is merely the selection of a known alternate coloring for the advantage of enabling safe night time agricultural operations as taught by Skelty (Skelty Col. 1 line 1-26).

For the reasons stated above for claim 26, claim 32 is not obvious over Hansford in view of Davis and Skelty.

Claims 26-30, 38 and 52 are rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 6,324,781 to Stevens in view of U.S. Patent No. 5,387,745 to Brendle.

Regarding Claims 26, 28, 29, and 30, Stevens teaches a colored mulch product (Stevens abstract line 2) consisting essentially of: a material comprising a fiber cellulose, clay, loam, sand, and/or a combination of same; a binding agent (Stevens Col. 2 line 2); and a dye and/or pigment (Stevens Col. 6 line 35). Stevens teaches a dye, but is silent on the dye **indicates** to a user environmental conditions of the soil where said mulch is placed; the dye **indicates** to a user the acidity of said soil; the dye **indicates** to the user the moisture content of said soil; or the dye **indicates** to a user the chemical content of said soil.

However, Brendle teaches that is old and notoriously well-known to use color (i.e. dye and/or pigment) in agricultural applications as an indicator, a label, a marker. Brendle is cited **merely to teach** that is known **to use color as an indicator of a particular characteristic of a parcel of land.** Purely as an example, in the case of Brendle, it is an area of land that receives a coating of a chemical composition that was pre-treated with a colorant (Brendle abstract and Col. 2 line 21-40). In other words, Brendle can apply to teaching an area of land that receives a coating of mulch composition that was pre-treated with a dye/pigment. It would have been obvious to one of ordinary skill in the art to modify the teachings of Stevens with the teachings of

Brendle at the time of the invention for the advantage of ease of distinction and the known advantage that the presence of color has been found that misapplications of substances is more easily avoidable as taught by Brendle (Brendle Col. 2 line 58-60) (i.e. distinction of knowing where a pesticide has been applied, knowing where a particular species/variety of plant has been planted, etc). It is generally knowledge to one of ordinary skill in the art that different plant varieties require different soil conditions. Thus, it would have been obvious to one of ordinary skill in the art to use a green colored mulch to distinguish where grass seed was plant and a red colored mulch to distinguish where tomatoes were planted. These two colors would inherently indicate different soil conditions since grass and tomato plants require different levels of moisture, different levels of acidity, and different levels of fertilization. Using color as an indicator/marker of any property, process, or treatment it is an obvious modification for one of ordinary skill in the art as supported by Brendle.

Stevens teaches a dye for aesthetic reasons only. Brendle only teaches using the dye to show where a treatment of the soil has been placed, such as where a pesticide has been sprayed. The combination of Stevens and Brendle only teaches a user that a dye can be placed on an agricultural location to show where chemical treatment was placed. The dye itself does not show the environmental conditions of the soil, indicate the acidity of the soil, indicate the moisture content of the soil or indicate the chemical content of the soil. Therefore, Claims 26 and 28-30 are not obvious over Stevens in view of Brendle.

Regarding Claim 27, Stevens as modified teaches the mulch comprising; nitrogen, phosphorous, and potassium fortifiers (Stevens abstract last line).

For the reasons stated above for claim 26, claim 27 is not obvious over Stevens over Brendle.

Regarding Claim 38, Stevens as modified teaches the mulch is the same or similar color of an actual plant, flower, fruit, or vegetable of a seed planted with the mulch (Stevens Col. 6 line 37).

As stated previously, Stevens states that "for example, the color may be green to match a lawn or grass area." Claim 38 requires that the mulch be the same or similar color of an actual plant, flower, fruit, or vegetable of a seed planted with the mulch to indicate what is planted underneath the mulch. Here Stevens teaches making the mulch mat look like a grass or lawn area, not that the mulch match the color to indicate what plant is planted under the mulch. Stevens does not teach having any seed under the mulch. Stevens purely paints the mulch for aesthetic reasons, to make the mulch mat look green like grass. If a tomato plant was planted under the mulch, Stevens would still have the mulch mat being green and not red to match the color of the vegetable. Therefore, claim 38 is not obvious over the prior art.

Regarding Claim 52, Stevens as modified teaches a method of placing colored mulch on top of soil; inherently changing the colors of the mulch based on the condition of the soil since when it rains, rain is an element of ambient weather conditions, there is more water in the soil objects tend to appear vibrant, but as the object dries (i.e. as it losses the nutrient water) it will inherently fade. Thus the colors inherently change based on the moisture conditions of the soil.

Stevens is silent on adding chemicals to the soil based on the color of the mulch. However, on one hand, it is old and notoriously well-known in the art of plant

husbandry to observe and test soil conditions to see if they meet the desired parameters. It would have been obvious to one of ordinary skill in the art, at the time of the invention, if they observed that the mulch was faded in appearance because of reduced moisture levels, that one of ordinary skill in the art would obviously know to add the chemical (i.e. water) to improve the moisture conditions depending on the needs of plant varieties located in that area. On the other hand, it is old and notoriously well-known to use color as an indicator as discussed in the preceding paragraphs. If grass was planted with the green colored mulch it would be obvious to one of ordinary skill in the art to add chemicals to that area to meet the needs of grass.

Claim 52 requires a method for adjusting the chemical content of soil comprising: placing a colored mulch on top of soil; changing colors of the mulch based on condition of the soil; and adding chemicals to the soil based on the color of the mulch. The claim requires that based on the color of the mulch a certain soil condition exists which requires chemicals to be added. Neither Stevens or Brendle teaches the mulch indicating to the user the condition of the soil to the user. Further, neither Stevens or Brendle teach adding chemicals to the soil. Although it is well known to observe and test soil conditions, it is not well known that the mulch provide the indicator of the soil conditions to the user so that the user knows the condition of the soil and what chemicals need to be added. Therefore, claim 52 is not obvious over Stevens in view of Brendle.

Claim 32 is rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 6,324,781 to Stevens in view of U.S. Patent No. 5,387,745 to Brendle as applied to claim 26 above, and further in view of U.S. Patent No. 5,734,167 to Skelty.

Regarding Claim 32, Stevens as modified teaches coloring the mulch, but is silent on the dye is florescent. However, Skelty teaches it is old and notoriously well-known to dye agricultural products with florescent dye allowing the mulch to glow in the dark (Skelty Col. 1 line 35-45). It would have been obvious to one of ordinary skill in the art to further modify the teachings of Stevens with the teachings of Skelty at the time of the invention since the modification is merely the selection of a known alternate coloring for the advantage of enabling safe night time agricultural operations as taught by Skelty (Skelty Col. 1 line 1-26).

Regarding claim 32, for the reasons stated above for claim 26, claim 32 is not obvious over the prior art.

Claim 47 is rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 4,067,140 to Thomas in view of U.S. Patent No. 5,387,745 to Brendle.

Regarding Claim 47, Thomas teaches a colored mulch product (Thomas abstract) comprising: a material comprising a fiber cellulose (Thomas abstract first line), clay, loam, sand, and/or a combination of same; a binding agent (Thomas Col. 1 line 30 "wetting agent" and Col. 4 line 35-41); and a dye and/or pigment (Thomas Col. 1 line 35) produced by a lifting and tumbling agglomeration operation (Thomas Col. 2 line 65-66). Thomas teaches adding fertilizer to the mulch mixture (Thomas Col. 1 line 15). Thomas is silent on the dye indicates to a user the environmental conditions of the soil where the mulch is place. However, Brendle teaches the use of dye/color as indicator that a chemical was applied to a particular area (Brendle abstract) e.g. fertilizer (Brendle Col. 1 line 21). It would have been obvious to one of ordinary skill in the art

to modify the teachings of Thomas with the teachings of Brendle at the time of the invention to prevent damaging overlapping of treatment of an area (Brendle Col. 1 line 26).

Claim 47 requires said dye indicates to a user environmental conditions of the soil where said mulch is placed. Thomas does not teach that the dye indicate to the user environmental conditions. Brendle only teaches that a dye or color can indicate to a user that a chemical was applied to a particular area. Brendle teaches that you can apply, for example, a fertilizer to an area, then color the area red to show that a fertilizer was added. Neither Thomas nor Brendle teach that the dye indicate to the user the environmental condition such as a lack of fertilizer. Therefore claim 47 is not obvious over Thomas in view of Brendle.

Claim 50 is rejected under 35 U.S.C. 103(a) as being unpatentable over U.S. Patent No. 6,324,781 to Stevens in view of U.S. Patent No. 5,697,984 to Swatzina et al.

Regarding Claim 50, Stevens teaches a colored mulch product wherein the color, but is silent on the mulch product faces or disappears in response to a lack of fertilizer in the mulch. Stevens teaches the mulch product is made up of fertilizer (Stevens abstract last sentence), mulch plus fertilizer makes a mulch product. Swatzina teaches it is old and notoriously well-known to color fertilizer (e.g. red fertilizer Swatzina). One of ordinary skill in the art would be motivated to modify the teachings of Stevens with the teachings of Swatzina at the time of the invention for a desired aesthetic design. Stevens as modified by Swatzina, i.e. the selection of red fertilizer, would inherently

teach that as the red disappears or fades from the mulch the fertilizer is disappearing too.

Stevens teaches a dye which the Examiner admits is not an indicator as taught in the claims of the patent. Swatzina teaches the use of a dye for preparation useful in printing inks. Therefore the combination of Stevens in view of Swatzina does not teach that a color would show whether a fertilizer is disappearing. Therefore Claim 50 is not obvious over Stevens in view of Swatzina.

Applicant believes that the application is now in condition for allowance.

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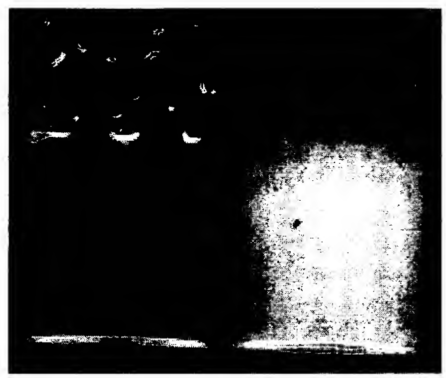
Faster, Better, Cleaner?

New liquids take aim at old-fashioned chemistry

Jessica Gorman

With increasing frequency, today's chemists are sending their students off in search of Victorian-era scientific reports. These obscure, 19th-century references to the work of organic chemistry's earliest practitioners are now appearing among the endnotes of an exploding number of present-day journal articles.

The reason? Researchers have recently become focused on recapitulating a century's worth of chemistry in an utterly new way. This time around, they hope to use a tantalizing new repertoire of solvents, known as ionic liquids, that can get the job done without the stink, mess, pollution, and toxicity of the workhorse solvents that have characterized much of organic chemistry so far.



Fluorohexane floats on top of a conventional ionic liquid (left). However, adding a small amount of a task-specific ionic liquid that acts like a detergent enables the fluorohexane and the conventional ionic liquid to mix into a yellow emulsion (right).
Davis

This research looks forward, as well as backward. The odd new liquids, which ultimately could be made in countless variations, are not just new solvents for old reactions. They're also leading to new chemical processes, tools for environmental cleanup, and novel materials.

And there's another promising aspect to these environmentally friendly liquids: Industry seems quite excited about them. "People have started to see the glimmer of what kinds of opportunities they offer," says Robert Morland, a chemist at the North American office of British Petroleum in

Naperville, Ill. "If you look at just the number of papers and patents in ionic liquids and plot that versus years, it's gone up exponentially."

Ionic solutions

So, what are these materials that could blend environmental gentleness with industrial innovation? Water and organic solvents, such as toluene or dichloromethane, the stuff of household paint remover, are made of molecules. Ionic liquids, by comparison, are made of positively and negatively charged ions—much the way table salt, sodium chloride, contains crystals made of positive sodium ions and negative chlorine ions, not molecules.

While table salt doesn't melt below 800°C, ionic liquids remain fluid at room temperature. In fact, ionic liquids generally are liquid from about –100°C to 200°C.

Theoretically, a trillion ionic liquids are possible, says Kenneth R. Seddon, a chemist at the Queen's University of Belfast, Northern Ireland who runs an ionic liquid research center there known as QUILL, an acronym for Queen's University Ionic Liquid Laboratory.

To make an ionic liquid, researchers can select from dozens of small, negatively charged ions, or anions, such as hexafluorophosphate ($[PF_6]^-$) and tetrafluoroborate ($[BF_4]^-$), and hundreds of thousands of larger, positively charged ions, or cations, such as 1-hexyl-3-methylimidazolium or 1-butyl-3-methylimidazolium, says Seddon. Ionic liquids are thus "designer solvents," he says. Chemists are free to pick and choose among the ions to make a liquid that suits a particular need, such as dissolving certain chemicals in a reaction or extracting specific molecules from a solution. Seddon's lab has about 130 of the liquids on its shelves already.

Researchers studying ionic liquids believe that they remain liquid at room temperature because their ions don't pack well. Combining bulky, asymmetrical cations with smaller, evenly shaped anions is "like gluing an octopus to a basketball," says Morland. This leaves the ions disorganized, without a regular structure—in other words, liquid.

In contrast, the sodium and chlorine ions in table salt are like oranges in a crate. They pack closely into solid, crystalline structures because they have similar sizes and shapes, says Morland.

Unlike typical organic solvents, ionic liquids tend not to give off vapors, so researchers say they're less hazardous and more convenient in the laboratory, and they're less likely to pose air pollution problems. What's more, chemists have found that they can extract products and recover chemical catalysts from ionic liquids easily and then recycle the liquid to use over and over.

Reactions that occur in organic solvents have been the standard way to make countless products. Now, many of these time-tested reactions have been repeated anew in ionic liquids, says Seddon. The list of successful reactions completed in the new liquids rings familiar to any college organic chemistry student: hydrogenation, nitration, halogenation, Diels-Alder, Friedel-Crafts, and on and on. These are the fundamental reactions by which raw chemical ingredients become medicines, plastics, cosmetics, fuels, and thousands of other materials.

As viscous as water—or a little more so—ionic liquids are easy to work with, says James H. Davis Jr., a chemist at the University of South Alabama in Mobile.

"Anybody anywhere can make them and handle them," says Davis. A chemist can basically take any organic reaction out of a textbook and try it in an ionic liquid.

A hot topic

Ionic liquids may be a hot topic for chemists now, but when they were first studied they were literally hotter.

The earliest ionic liquids in the literature were probably created unintentionally in the late 19th century, says John S. Wilkes, a chemist at the U.S. Air Force Academy in Colorado Springs, Colo. He's found references to a red oil, probably an ionic liquid, that appeared during certain reactions.

Later, during the 1940s, aluminum chloride-based molten salts were used for electroplating, usually at temperatures of hundreds of degrees Celsius.

In the early 1970s, Wilkes and his colleagues began much of the work behind today's ionic liquids revival. They had been trying to develop better batteries for missiles, nuclear warheads, and space probes. The team's batteries required molten salts to operate, but such substances were hot enough to damage nearby materials. So, the chemists looked for salts that remain liquid at lower and lower temperatures. Eventually, they identified one that's liquid at room

temperature.

The work plodded on into the early 1980s, as Wilkes and his colleagues continued to improve their ionic liquids for use as battery electrolytes (SN: 4/24/82, p. 282). Then, Seddon traveled to the Air Force lab for a visit.

It struck Seddon that there were broader opportunities for these materials, particularly as solvents for organic reactions. He and a small community of researchers began making ionic liquids, testing their properties, and trying out old reactions in them. Results from this work eventually encouraged Seddon to found QUILL in 1999.

After talks with Seddon, Robin D. Rogers, an ionic-liquid chemist at the University of Alabama in Tuscaloosa, helped establish in 1998 the Center for Green Manufacturing, which has become another stronghold in the fledgling field. *Green* refers to processes that are effective but sidestep the environmental drawbacks of much traditional industrial chemistry.

Although interest in ionic liquids picked up in the late 1990s, Seddon and Rogers still had trouble rounding up 50 or so chemists to attend an April 2000 workshop in Crete on the topic.

Recently, however, interest in ionic liquids has skyrocketed. For example, Rogers reports that at the American Chemical Society meeting in San Diego last April, more than 275 people jammed into the meeting room on the first day of a 5-day symposium in which more than 80 chemists gave oral presentations on ionic liquids.

Ten years ago, chemists published about 10 papers a year on ionic liquids, adds Seddon. Today, it's about 10 papers a week.

And that doesn't represent the unreported work going on at corporate labs, adds Al Robertson, a chemist at Cytec in Niagra Falls, Ontario. "It's not just a passing interest anymore," says Robertson, whose company has developed a family of phosphonium-based ionic liquids.

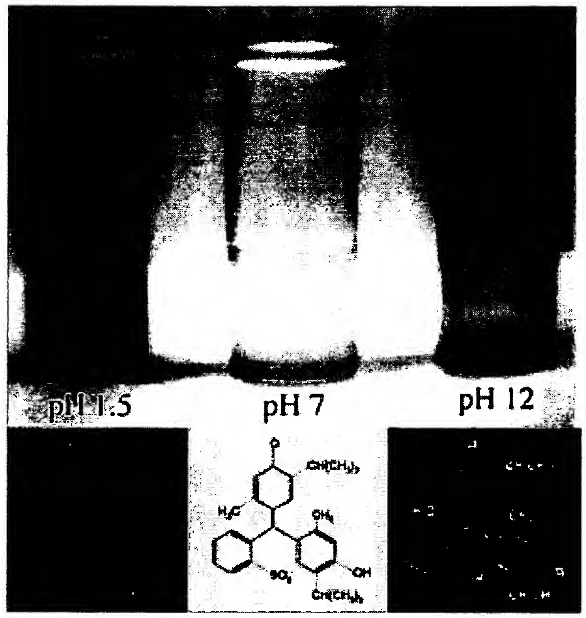
A hard sell

Ionic liquids might make chemical processes cleaner, but unless the liquids can improve a company's bottom line, they would be a hard sell to management and many stockholders.

In fact, there are plenty of commercial incentives for industry to embrace such research, according to Morland of BP. One of them is that compounds dissolve in ionic liquids in ways that enable chemists to separate products easily later, he says. Another is that ionic liquids can host a variety of catalysts in more convenient, effective, and recyclable ways than can conventional organic solvents.

Moreover, some reactions occur at a faster rate or yield a more valuable proportion of products and by-products when done in an ionic liquid, says Morland.

The expectation that ionic solvents will be environmentally benign also has "a significant positive impact," Morland adds. If BP could use ionic liquids in its processes, it could decrease use of polluting volatile organic solvents, he says. Furthermore, ionic liquids could make reactions more efficient, thus reducing waste.



Decreasing acidity—that is, increasing pH—can move dye molecules from an ionic liquid to water: At high acidity, a dye called thymol blue is actually red and prefers an ionic liquid to the water layer above it (left). As a chemist decreases the acidity by adding sodium hydroxide (middle and right), the dye changes color and moves upward. Chemical structures appear below photo.
A. E. Visser *et al./Green Chemistry*

Jimmy W. Mays, a chemist at the University of Alabama at Birmingham, has learned just how interested industry has become. "I gave a talk at the [American Chemical Society] meeting in San Diego back in April, and I was mobbed after the talk," says Mays, who uses ionic liquids to make polymers. "I've had calls from people at companies saying, 'Look, we want to give you money to work on this.'"

More than just green

Recently, researchers such as Mays have discovered that ionic liquids are more than just green versions of organic solvents. They've been shown to support delicate enzyme-catalyzed reactions, to make new materials, and to conduct

heat efficiently.

Wilkes has moved beyond batteries to discover that an ionic liquid will dissolve the black rubber of discarded tires, which is hard to do with organic solvents. The polymers in the ionic liquid can then be recovered for recycling, he says.

Other researchers have found still more applications for ionic liquids. Consider Mays. He got caught up in the research 2 years ago after he obtained some ionic liquids from Rogers. He immediately found that he could use them to make commercially important polymers, such as the ones in Styrofoam and Plexiglas, 10 times faster than with traditional solvents. Moreover, the resulting polymers had extraordinarily high molecular weights, which leads to high-quality materials.

Since then, Mays has used ionic liquids to make block copolymers—compounds that have a long stretch of one polymer attached to a long stretch of another—including ones that can't be made in any other way. He can even make so-called statistical copolymers, which have particular patterns of individual units in the polymer chain.

The University of South Alabama's Davis also stumbled into ionic-liquid chemistry. He was working with imidazolium salts when he read that the salts are commonly used in ionic liquids. He started out trying to perform one traditional organic reaction in an imidazolium ionic liquid, and he succeeded.

Now, Davis makes task-specific ionic liquids—substances that act as both solvent and catalyst for specific chemical jobs. He attaches an ionic liquid's bulky cations to groups of atoms that tend to bind to particular metal contaminants, such as mercury or cadmium.

"Literally, the arms on the cations reach up and grab the mercury and cadmium [from the water] and pull them into the ionic liquid," says Davis.

He's also altered cations to grab uranium and americium, which are two waste materials from nuclear weapons production. "This is potentially quite significant," says Davis, "because there are literally millions of gallons of contaminated water stored at places like the Hanford nuclear site" in Washington State.

Now, Davis has even developed ionic liquids that will pull carbon dioxide and hydrogen sulfide out of a gas. Natural gas often contains these impurities when it's discovered in the ground. Since it doesn't burn, carbon dioxide lowers the fuel

value of natural gas. Although hydrogen sulfide burns, it generates sulfur oxides that contribute to acid rain.

An ionic liquid could potentially even pull carbon dioxide, the most important of greenhouse gases, from factory exhaust. It might also yank carbon dioxide out of the confined air of the space shuttle or International Space Station, says Davis.

A happy compromise

With all their possible environmental and industry benefits, ionic liquids seem to offer a happy compromise. But hurdles remain before they can become major components of the chemical industry.

For one, the price of the liquids needs to fall. Organic solvents cost just a few cents per liter, while the new ionic liquids can cost hundreds of dollars for the same amount. However, ionic liquids may be recyclable, so the cost could be a capital expenditure, like buying a piece of lab equipment, says Mays.

And as more people use ionic liquids, some researchers argue, the price should go down.

Another obstacle is the current dearth of toxicologic data on these substances, says Rogers. Many researchers believe that ionic liquids pose little or no health danger, but studies must be completed before any of them can be proved safe and sold or used commercially.

And then there's the case of patents. Can someone claim the patent on a whole family of ionic liquids? Who owns the right to a company's valuable chemical reaction if the patent only lists organic solvents and not unforeseen ionic liquid solvents? Such problems will have to be worked out.

Finally, laboratory-scale experiments will need to be scaled up for factory-size processing—a trick that often quashes the promise of laboratory successes. A couple of pilot trials have taken place, but no one has yet taken the leap to full-scale commercial production using ionic liquids.

"If you look at the total cost of making [an ionic liquid]—raw materials, environmental impact, use . . . and getting rid of it—is it really better than an organic solvent?" asks Rogers. "These questions are still to be answered."

So, when might ionic liquids move into the mainstream? Cytec, for one, is waiting to see which ionic liquids generate a demand, says Robertson. If there is a market, he adds, the

company would be able to produce at least one of its own ionic liquids by the truckload.

Meanwhile, Seddon speculates that chemistry textbooks will add ionic liquids in the next year or two. Then, new crops of chemists will enter their professional lives with ionic liquids on their minds. Within a decade, Seddon expects, every academic and industrial chemist will have a jar of ionic liquid within reach, and some chemical companies will use tanks of it.

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